

(6.) (7.) (8.)

With A. Stuart's Complements.

ON SOME IMPROVEMENTS IN THE METHOD  
OF GRAPHICALLY RECORDING THE VARI-  
ATIONS IN THE LEVEL OF A SURFACE  
OF MERCURY, e.g. IN THE KYMOGRAPH  
OF LUDWIG. By T. P. ANDERSON STUART, M.D.

THE CIRCULATION KYMOSCOPE, AN ARRANGE-  
MENT FOR DEMONSTRATING MANY OF THE  
PHYSICAL PHENOMENA OF THE CIRCUA-  
TION. By T. P. ANDERSON STUART, M.D.

THE INTERFERENCE KYMOSCOPE, AN APPA-  
RATUS FOR DEMONSTRATING MANY OF  
THE PHENOMENA OF WAVE MOTION. By  
T. P. ANDERSON STUART, M.D.



*Reprinted from the Journal of Physiology.*

*Vol. XII. No. 2, 1891.*





[From the *Journal of Physiology*, Vol. XII, No. 2, 1891.]

ON SOME IMPROVEMENTS IN THE METHOD OF  
GRAPHICALLY RECORDING THE VARIATIONS IN  
THE LEVEL OF A SURFACE OF MERCURY, e.g. IN  
THE KYMOGRAPH OF LUDWIG. By T. P. ANDER-  
SON STUART, M.D., *Professor of Anatomy and Physiology,*  
*University of Sydney, N. S. W.* Pl. V. Figs. 1, 2.

FEW can have worked with the ordinary form of Ludwig's Kymograph without having been annoyed by the frequency with which the mercury rises above the float of the style which then refuses to move till it is withdrawn by hand, the record being meanwhile interrupted. I think I am right in saying that this is the most troublesome defect in the whole apparatus. About eighteen months ago, when engaged in some experimental work involving the use of the apparatus, I found progress so much impeded by the old trouble that I determined to get over it if possible, and succeeded so completely that since that time I have never had a failure. The float now very rarely sinks below the mercury surface, and if from a very sudden and great rise the mercury does get up alongside or over the float the latter immediately rises again so that, the float being self-righting, the style never needs to be touched by the hand.

During my attempts to attain this result I soon became convinced that the first thing to do was to get rid of the long point of bone which in the ordinary form of float sinks deeply into the mercury so as to carry the steel style. It was quite evident that the cause of the sticking of the style in the manometer was the mercury collecting on one side of the float and then, in striving to assume the spherical form, jamming it firmly against the wall of the manometer tube. This action is strikingly shown if a wide cylindrical test glass be filled with mercury and a rod be pushed into the mercury and moved about. The rod will get against the side of the vessel and be firmly held there by the mercury "folding round it." This is a very striking little experiment. It shews that the friction in the Kymograph apparatus as it is usually made is not friction in the ordinary sense at all, and it explains how it so often happens that after everything has been made clean and every precaution has been taken to ensure success still the style will

stick. Thus the desideratum was a float and style which would be strong enough to do the work and which yet, with the weight of the pen and its friction on its guide and on the paper superadded, would be light enough to offer so little resistance to the rise of the mercury that the float would not be apt to get below the mercury's surface. The weight of the ordinary form is about 4·4 grammes as compared with 1·8 grammes, the weight of the one which I am about to describe.

The material which after many trials proved most satisfactory was glass. A glass tube melted and rapidly drawn out yielded a long, light, straight and smooth style with a bulb at the end. Around the upper part of the bulb is fixed by sealing-wax a collar of glass tubing, just large enough to move easily within the manometer tube, Pl. V. fig. 2. This collar is important, for its lower edge catches the mercury in its rise, so that float and mercury rise together, and it likewise keeps the bulb of the float on the centre of the mercury surface, so that the tendency for the mercury to go up on one side of the float is greatly diminished. It might be said that such a style is too frail, but it is rigid enough vertically—the direction in which rigidity is wanted, while laterally it is so elastic that with ordinary care it does not readily break. Further, since it does not stick in the manometer, one does not need to handle it during an experiment and in point of fact I have had one in use now for a long time.

For a perfect result, however, this improved style is not sufficient by itself, since the ordinary pen-guide and the ordinary paper both contribute their shares of undue resistance. The usual way of keeping the pen against the paper is to have a weight hanging by a thread over the pen. Now a little reflection will convince one that this method is bad, for as the pen rises the obliquity of the upper part of the thread increases and so the pressure of the thread on the pen increases too. Thus if the pressure be just enough when the pen is low it is too much when the pen is high. Obviously then the degree of pressure of the pen on the paper cannot by this method be constant. Further, from the rising and falling of the pen or from accidental contact with the thread or the weight, oscillations of the weight are very common and these too introduce variations of the pressure of the pen on the paper. Lastly the quicker and higher the rise of the pen the greater during the rise is the extra pressure of the pen on the paper. The evil of the extra pressure from these causes is that the hindrance to the rise of the style being unduly great, the mercury now rises alongside the float which forthwith becomes jammed.

In order to get an even pressure of the pen I have introduced a guide of horse-hair—silk would answer well enough though I think the hair is best—attached above to the ordinary wire-guide sent out with the revolving cylinders, but fastened below to a spiral brass spring, which can be moved along a round brass rod which in turn is moveable along another such rod, screwed into the manometer frame and may be fixed in any position, Pl. V. fig. 1. Thus the hair may be placed in any position at either end, and kept at an even tension. If the hair be arranged parallel to the surface of the paper the pen will write at any height and always maintain exactly the same pressure on the paper.

This arrangement, as it happened also permitted the re-filling of the pen, which is the ordinary one used in such apparatus, without in any way interrupting the record. Since the pen guided by the hair is always in the same practically vertical line, one has but to hold a pipette above the pen to let the ink drop evenly in—a great convenience sometimes.

The horse-hair does not rest directly on the pen, but plays in a little wire loop composed of one and a half turns of an open spiral stuck into the cork cylinder that carries the pen and is in turn carried by the style. This wire loop can be readily withdrawn from the cork and exactly replaced, so that it is very nearly as simple as letting the thread rest over the pen directly. Of course the hair-guide presses outwards so as to take the point of the pen inwards. The turns of the spiral being open the wire loop can be applied to or removed from the hair without undoing the ends of the latter.

A final source of undue resistance is the quality of the paper. My experience is that the paper usually sent out in the rolls is of quite unnecessarily rough surface, is poor in quality and takes up too much ink. In Europe I suppose one would have no difficulty in procuring a better article—here I was at my wits' end till it occurred to me that some of our newspapers were printed on fairly smooth paper of such good quality that it would neither offer undue resistance to the movements of the pen nor take up so much ink as to prematurely empty it. I therefore asked a friend, a newspaper proprietor, to keep me the end of a roll of paper. Thus I got a roll some 12 inches in diameter and 42 inches wide which I sawed into convenient widths. I found this paper to be the best I had ever seen for the purpose.

The total result of these improvements of method is that so far as the recording apparatus is concerned one is now able to practically guarantee the success of an experiment.

THE INTERFERENCE KYMOSCOPE, AN APPARATUS  
FOR DEMONSTRATING MANY OF THE PHENO-  
MENA OF WAVE MOTION. BY T. P. ANDERSON  
STUART, M.D., (*Edin.*) *Professor of Physiology, University of*  
*Sydney, N.S.W. Australia.* Pl. V. Figs. 4—7.

THE construction of the arrangement is as follows:—a tube, say 24 feet long, is coiled into a spiral of uniform diameter and into each turn is inserted a vertical glass tube about 14 inches high so that these manometer tubes stand in a row side by side. Gas-pipe with a lumen of  $\frac{5}{16}$  in. is convenient for the spiral tube. The junction of the manometer tubes with the spiral tube is by little brass tubes (of uniform internal diameter) soldered into the spiral tube, and on these brass tubes the glass manometer tubes stand—joined to the brass tubes by a piece of rubber tubing. At their upper ends the manometer tubes are kept in position by being tied to a brass rod stretching from one side of the frame to the other, and covered with a piece of rubber tubing to avoid risk of breaking the glass tube against the brass rod. The series of manometer tubes should be all of nearly equal lumen, and each tube should be as nearly as possible of uniform lumen throughout its own length. The upper ends of the manometer tubes have their edges rounded off in the blow-pipe, but the lower ends should be left as they are broken, for in rounding the lower end off the lumen might be diminished there. Through the nozzle the spiral tube is now filled with water already coloured by ammoniacal carmine solution to make it visible from a distance; this is aided also by having a white cardboard background for the series of manometer tubes. The coloured water is filled in till it stands about one-third of the manometer tubes, and the “normal” level of the water may readily be indicated by a readily adjustable band of Berlin wool tied round the series.

Pressure changes in the spiral tube are of course at once indicated by corresponding changes of level of the water in the manometer tubes. Now since the pressure change at any point in the spiral tube spreads as a wave, it follows that the changes of level in the manometer tubes

should also spread in that form. Had however the spiral tube been kept straight the length of the wave in proportion to its height would have been so great that the wavelike form of the alteration of level in the series of manometer tubes would not have been manifest, but by shortening the wave, taking not the whole wave but samples of it, so to speak, at equal distances and bringing the samples close together, the wave like form of the pressure change as it is propagated along the tube is at once and strikingly manifest. It is in order to get the samples close together that the tube is wound in a spiral. A convenient diameter for each coil of the spiral is one foot. Air bells lodging in the manometer tubes are easily dislodged by a wire, but if the manometers be of tube wide enough the bells rise spontaneously. In the simple form of Kymoscope, Pl. V. fig. 4, the end of the spiral tube is closed without any noteworthy inconvenience arising from the reflex wave; but the circuit need not be closed, and I have devised forms of the Kymoscope for physiological teaching purposes in connection with the circulation of the blood in which a real circulation of the coloured water is kept up. In this case of course a set of valves must be introduced; such a modification of the Kymoscope is described in the following paper.

The form of the wave is admirably displayed by the simple Kymoscope where alternately compressing and letting go the rubber bulb creates the necessary pressure changes—positive and negative. The fact that the manometer tubes are open above permits such an unduly great change of level in the first tubes that the change is unduly little in the last tubes. This inconvenience were it worth while can easily be obviated in one of three ways, and for some purposes it may be desirable, but having made the compensation in all three ways I find that after all for most purposes it is not worth while. These ways are:—  
(1) make the inlets to the first tube the narrowest and gradually widen the inlets along the series; (2) have the first manometer tubes the narrowest and gradually widen the tubes along the series; (3) have an air vent at the upper end of the tubes, smallest in the first and gradually increasing along the series. The air vent may be a small stopcock or a thin metal cap perforated by a hole which gradually widens along the series of tubes. The method of carrying out the adjustment is worth noting. A considerable volume of water is allowed to run freely into and out of the spiral tube by alternately raising and lowering a reservoir; when no adjustment has been carried out the tops of the water columns in the manometer tubes rise or fall in a straight but

very oblique line: the rise and fall in the first tube is now limited to the requisite extent, and after this the others are limited so that the lines of rise and fall are straight lines but less oblique than before. The first mode of adjustment is easily accomplished by simply compressing the brass tube connecting the spiral and the manometer tube, and this done in the first few tubes is all that will be needed for most purposes. Where the size of the wave is to be shewn, two limits are to be marked, the crest and the hollow; and two wool bands may be used.

For the demonstration of interference the Kymoscope is made with two coils ending in a common coil. Here accurate pumping is needed, and this is secured by the double piston pump shewn in the figure, Pl. V. fig. 6. One piston is worked by an arm, the other by a disc. Holes in the arm permit variation in the stroke of the piston and therefore, the pump tubes being of equal internal diameter, variation in the volume of water alternately thrown out and drawn in. The disc similarly permits variation in volume but likewise variation in the time of throwing out or drawing in the water. In this way two waves of the same or of different magnitudes and of corresponding or of different phases are sent into the two first manometer tubes and so their relation made visible; then they pass into the common coil, and the resulting wave is at once visible. Slots instead of holes in the arm and disc would be more perfect theoretically, but would be so much more troublesome to adjust that the holes are better. The pump may be driven by hand or motor.



THE CIRCULATION KYMOSCOPE, AN ARRANGEMENT  
FOR DEMONSTRATING MANY OF THE PHYSICAL  
PHENOMENA OF THE CIRCULATION. BY T. P.  
ANDERSON STUART, M.D., *Professor of Anatomy and Physi-  
ology, University of Sydney, N. S. W. Australia.* Pl. V. Fig. 3.

THE principle of this instrument has been described in the preceding paper.

The line of normal pressure is easily shewn to an audience by a band of white Berlin wool which surrounds the tubes and may be adjusted. When it is a question of size of waves, and thus two limits are to be marked, then two bands may be used—an upper and a lower, so that the oscillations between the two are at once seen.

The spiral tube may be elastic or rigid; in fact, however even the rigid tube is elastic, for of course the manometers being open and the liquid rising within them against gravitation makes the rigid spiral into an elastic one; only instead of being elastic all round and all along it is elastic only at the points whence spring the manometers. Upon the whole the rigid tube is most serviceable for it is more durable, and one can so easily insert stopcocks instead of elamps for the vasomotor nerves' action.

With the manometer tubes open above the oscillation is large in the first tubes and diminishes rather rapidly in the rest. This however can be controlled in various ways, e.g. (1) The bores of the manometer tubes may increase onwards in the series. (2) Air vents may be fixed at the top of the tubes permitting much or little air to pass through as the case may be. Thus an air cushion above the column of liquid is provided on the one hand limiting the movements of that column and on the other by its elastic recoil handing on the greater force to raise the columns in the next following tubes. (3) The inflow to the manometer tubes may be regulated by compressing the brass connecting tubes or by intercalating stopcocks between the spiral tube and the manometer tubes. This upon the whole is the best means, if the adjustment is wanted for any special purpose, but practically it may usually be dispensed with.

The actual method of adjustment is as follows. Alternately raise and lower a tubulated bottle containing water so that the water may alternately run into and out of the tubes. Now turn the first stopcock so that the first tube shews a column of the desired height, and then adjust the rest, one after the other, so that eventually the liquid rises and falls in the series of tubes with the tops of the columns in a horizontal line; this indicates that the quantity of fluid entering or leaving the tube in a given time is the same for all the tubes in the series, and so the adjustment is complete.

The nozzle permits the ready filling of the instrument with water. Should air-bubbles get into the tubes—and the latter are so narrow that the air does not readily float up—it may be dislodged by a wire, the twisted wire used for picture-hanging is very good for this purpose. It is best to use tubes of such width that the air-bubbles come up of themselves—say  $\frac{5}{16}$  in. internal diameter.

The instrument may be modified in various ways so as to serve different ends, as will suggest themselves to anyone using it for teaching. For instance, by introducing stopcocks into the spiral, or clamps on an elastic tube and setting these at a mid position, the effect of the vasoconstrictor or vasodilator nerves on the blood pressure in advance of and behind the affected segment of vessel may be demonstrated. By inserting into the middle coils any resistance, such as the peripheral resistance, say by pieces of sponge or of wire-gauze, the rapid fall of pressure in the capillary area is at once made visible, so that the pressure diagram given in many books as a mere scheme is now realised. The liquid is best coloured with some alkaline carmine solution, so that it may be more visible, especially if the background be white cardboard. When one end of the spiral is connected with a reservoir and the other end is left open, the straight line of diminishing pressure is at once noted, and instructive changes follow the contraction or dilatation of inflow or outflow. When the inflow is intermittently interrupted a pulsation is seen at the inflow end but no pulsation at the outflow. When however the spirals are made part of a circuit in which a rubber bulb with valves—to represent the ventricle, i.e. the heart—is placed, then the rhythmic contraction of the bulb is seen to cause two pulses—an arterial one from the force-pump action, a venous one from partly a suction-pump action of the bulb and partly a simple damming back or stoppage of the flowing stream. That the latter is at work one sees by putting into the outflow tube with either a constant or intermittent inflow a rigid, say a brass, tube and intermittently closing

the outflow with say a coin—here there is no suction and no forcing back—simply a stopping of the flow, and yet a pulsation is well seen.

The fact that the normal arterial and venous pulses are not synchronous is well seen when the manometer tubes are arranged in a circle; then the first (arterial) tube and the last (venous) tube stand side by side, and the alternation is now very instructive.

The force and frequency of the stroke, the volume of fluid ejected, and so on, may all be varied so as to imitate the variations of the heart's action and its effects on blood pressure. When the heart is not working then the pressure becomes equal all round.

The difference of the heart's action as a force- and a suction-pump is well seen. First compress the bulb and keep it so; only the positive arterial pulse is seen. Now let it expand, and then only the negative venous pulse is seen. When the heart is working, the difference of pressure at the two ends is seen to be as the difference between positive and negative—not simply between more positive and less positive.

The disappearance of the pulse in the area of the small arteries and capillaries is strikingly shewn, as is also the gradual diminution of the pulse that leads up to this.

That the rate of flow of the stream is proportional to the difference of pressure as between the two ends is easily shewn by introducing a Lortet's Dromograph into one of the middle coils so that the index may be kept steadily deflected.

#### EXPLANATION OF PLATE V.

Fig. 1. The recording apparatus in working order.

Fig. 2. The style &c., enlarged to shew details.

Fig. 3. Circulation kymoscope :

- a. Nozzle for filling in the coloured liquid: a rubber tube about  $1\frac{1}{2}$  ft. long is slipped over the nozzle and held vertically: the liquid is poured into a funnel pushed into the upper end of the tube.
- b. Rubber ball representing the ventricle.
- c. Brass box containing the valves.
- d. Rubber ball: the tube traversing it is perforated: when the stopcock *e* is closed the valves are no longer in action, and the circulation kymoscope is thus converted into a simple kymoscope with a blind end shewing simply wave motion from one end of the coil. The author now usually omits this modification as he has sometimes found that it confused students. When the simple kymoscope

is wanted it is, upon the whole, better to have a separate piece of apparatus.

Fig. 4. Interference kymoscope:

- a.* Nozzle for filling as in fig. 3.
- b.* Manometer tube from coil 1.
- c.* " " " " 2.
- d.* " " " " 3 : commences the single series.
- l'.* Stopcock for cutting out coil 1 ; there is one on the other side for cutting out coil 2.

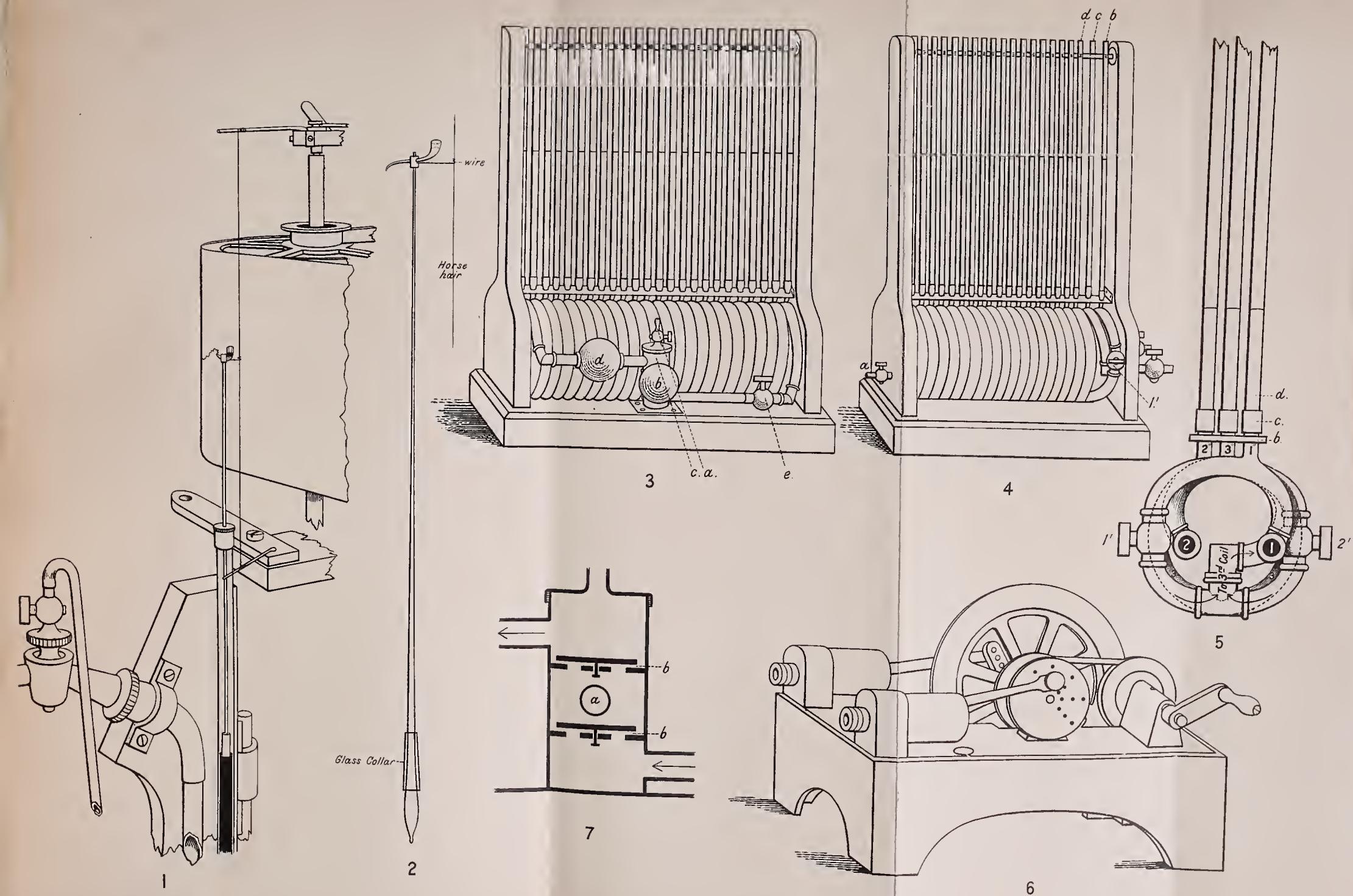
Fig. 5. Scheme of interference kymoscope:

- 1 and 2. Inlets to coils 1 and 2.
- 1' and 2'. Stopcocks by which either wave may be cut out so as to shew the other as it is when not interfered with.
- 1'', 2'', 3''. Brass tubes connecting the coils to the manometers.
- b.* Brass plate perforated to allow passage of brass connecting tubes : these are thus held accurately in position.
- c.* Rubber tube connecting the brass to the glass tubes.
- d.* Glass manometer tube.

Fig. 6. The double pump for use with the interference kymoscope.

Fig. 7. The valves.

- a.* Rubber bulbs attachment.
- b.* Valves—a shelf with a circle of large holes for the passage of the liquid and a central hole for a guiding pin to the valve flap. This is a piece of thick sheet brass. The opposed surfaces of the flap and shelf are ground on a plane surface, so that the fit is accurate, and the guiding pin must fit loosely, so that the weight of the flap will at once bring it down.





\*